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THE COLOR OF SOME JORDANIAN BUILDING LIMESTONES IN THE DRY AND WET STATES

Dr. Basem K. Moh'd

Department of Civil Engineering, Applied Science Private University, ASU, Amman, Jordan

ABSTRACT

*The color of twelve Jordanian building limestones assigned using the Munsell Rock Color Chart (MRCC), was found not accurate enough especially in the wet state. This is believed to be due the limited number of rock chips included in this chart. Hence the color, in the dry and wet states, was measured by a colorimeter using the L*a*b* color system. Color differences were expressed by ΔE and ΔC (chromaticity).*

In the dry state, the highest L and E values were recorded in a creamy white coquinal limestone and the lowest in travertine. Chalk recorded the highest a*, b* and C values, whereas a gray-black limestone has the lowest b*, E and C values. In the wet state, the creamy white limestone has the highest L* and E values and the lowest a* value. Chalk has the highest a*, b* and C values. The gray-black limestone has the lowest b*, E and C values.*

Upon wetting L^* and E decrease, while a^*, b^* and C increase. The highest ΔE occurs in the gray-black limestones, an intermediate change occurs in fine and coarsely crystalline limestones, followed by colored chalks. Other types of limestone have a low change in E. In the case of ΔC, the greatest change occurs in colored chalks, followed by the very fine-grained limestone, crystalline rocks and finally the fossiliferous limestones.

Four broad color fields (cream-white, gray-black, yellowish, and reddish-pinkish) can be distinguished in the ΔE-ΔC graph. The color in the wet state can be derived from that of the dry state using the graphs made in the present work.

Key words: Building limestone, color, wetting, drying, soaking, Jordan, L*a*b* color system.

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1. INTRODUCTION

A certain type of stone may be selected solely because of its attractive color (regardless of its durability and strength properties). Stones used in buildings in positions particularly exposed to water will have a different color from those in drier locations. When using stones of different colors adjacent to each other, staining problems should be taken into consideration. Thus color changes affect the aesthetics and sometimes the performance of building stone. Many building stones will vary in color even when obtained from a single bed. Hence, to avoid problems associated with color variation between individual building stone units, it is important that the variation in color be quantified.

Color is a three dimensional property. The different components of color are commonly referred to as lightness, hue and saturation. The change of stone color by weathering, staining, polishing, grinding and wetting may result in changing the value of one or more of its color components. Color, being a matter of perception and subjective interpretation, is clearly an aesthetic issue. Since descriptive expression of color is too complicated and difficult, the amount of variation, which may be encountered in the color of stone, should be quantified. The color of a rock has a composite character attributable to its mineralogy, grain size and, in the case of clastic sedimentary rocks, the type and amount of cement present. Since it is difficult to make a quantitative assessment of color by eye alone, it is important to use a chart or some other tool to describe the color accurately. The need for a standard method by which colors can be expressed led to the development of the Munsell Color System in the United States by A. H. Munsell which was first published in 1905 (Nickerson 1976a, b and c). This system evaluates color in terms of hue, value, and chroma. Hue refers to the basic color or a mixture of basic colors; chroma indicates the intensity of a particular hue, whereas the value indicates the degree of brightness or darkness of a color.

The complete Munsell notation for any chromatic color is written in terms of hue, value and chroma and it was selected by the Geological Society of America as a basis for its rock color chart. This represents a semi-quantitative attempt at color determination. In the present work, it was found that the Munsell rock color chart (MRCC) is not sufficiently accurate to quantify the changes in color upon wetting. A colorimeter employing the L*a*b* system was used to get more accurate results.

The early versions of this system were first developed by Hunter (1940) who was attempting to develop an instrumental colorimeter based on Judd's Maxwell Triangle (Judd, 1935; Maxwell, 1860). Improvements were made by Hunter (1942, 1958, and 1967), Scofield (1943), Nickerson (1950) and CIE (1976). Scofield introduced the symbols L (for lightness), a (for redness-greenness), and b (for yellowness-blueness). The color difference (ΔE) is expressed by

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{0.5}$$

and for chromaticity difference (ΔC)

$$\Delta C = [(\Delta a)^2 + (\Delta b)^2]^{0.5}$$

To convert Lab to CIE (International Commission on Illumination) XYZ system, the following equations are used (Hunter, 1975; Table 9)

$$Y=0.01\ L^2$$

$$X=0.9804\ (0.01L^2 + aL/175)$$

$$Z=1.181(0.01L^2 + bL/70)$$

While Y correlates with lightness, X and Z by themselves do not correlate with hue, saturation, depth, vividness, redness, yellowness-blueness, or with any visually meaningful attribute of color appearance (Hunter, 1975; Page 75).

The present work is part of a PhD Dissertation completed at the University of London (Moh'd, 1996) on evaluating some Jordanian building limestones as building stones.

2. MATERIALS AND METHODS

The Munsell Rock Color Chart (MRCC) of the Geological Society of America and an X-Rite 948 color meter were used to measure the colors of stone. The latter is a reflection spectro-colorimeter, which measures spectral reflectance from 400nm to 700nm in 20 nm intervals. It has a 0° illumination angle, a 45° viewing angle, and features a dual-beam, single light pulse compensation method to ensure accuracy.

The color of 12 stones was measured in 4-cm cubes in the dry and soaked states. At least 6 readings were taken from each cube (one reading from each face) in each state. Four to six cubes of each stone type were measured.

The studied limestones include chalk, travertine, conglomeratic limestone, and fossiliferous and non-fossiliferous varieties. Most of the studied limestones are almost pure carbonates, except Karak, Saham, and Hatem Stones (less than 15% SiO_2). The colors of the stone originally results in the depositional environment and then modified in the diagenetic and weathering environments.

3. RESULTS

The colors obtained for the stones using the Munsell Rock Color Chart (MRCC) (Table 1) proved to be inaccurate and mostly approximate. This is evidenced by the question marks shown in Table which lists (using the MRCC) the colors of some Jordanian limestones in both the dry and soaked states. The same problem of inaccuracy was faced by other workers and is believed to be due to the low number of rock color chips (40) in the MRCC. This led Folk (1969) to recommend the use of a soil color chart, published 1954, which, although it relies on the Munsell system, contains 248 color chips.

A more accurate method of quantifying colors is by using colorimeter. The different color attributes of the Jordanian limestones are summarized in Table 2. In the dry state the E value ranges from 62.99 in travertine to 86.17 in Hallabat. The rocks can be arranged according to their E value as follows (from highest to lowest): Hallabat, Hayyan, Hatem, Tafih, Sahrawi, Yanabi, Izrit, Ma'an A, Ballas, Ma'an B, Karak, and travertine.

Table 1 The colors of some Jordanian limestones using the MRCC. Question marks indicate the difficulty or impossibility of assigning an accurate color, after Moh'd (1996).

Stone	Dry	Wet
Ajlun	yellow grey (5 Y 8/1) to light greenish grey (5YR 8/1)	10 YR 7/2 ?
Hallabat	pinkish grey 5YR 8/1	yellowish grey 5 Y 8/1
Hatem	yellowish orange 10 YR 8/4 ?	slightly darker 10 YR 8/5 ?
Hayyan	pinkish grey 5 YR 8/1	yellowish grey 5 Y 8/1
Izrit	moderately orange pink 10 R 7/4	moderately red orange 10 R 6/6
Karak	light olive grey 5 Y 6/1	greenish grey 5 GY 6/1
Sahrawi Red	moderately orange pink (5 YR 8/4) to pinkish grey (5 YR 8/1)	moderately orange pink (10 R7/4) to very pale orange (10 YR 8/2)
Sat'h & Jaz.	pinkish grey 5 YR 8/1	yellowish grey 5 Y 8/1
Travertine	moderately yellow brown 10 YR 5/4 to 10 YR 6/4	?

In the wet state, the E value ranges from 45.87 (Karak) to 80.76 (Hallabat) and the sequence of rocks in descending order is as follows: Hallabat, Hayyan, Hatem, Tafih, Sahrawi, Yanabi, Ballas, Ma'an A, Ma'an B, Izrit, travertine, and Karak.

Table 2 Different color attributes of the Jordanian limestones after Moh'd (1996).

Stone Type	DRY					WET				
	L*	a*	b*	E	C	L*	a*	b*	E	C
BALLAS	77.05	2.91	9.16	77.65	9.63	66.15	6.89	23.97	70.93	24.97
HALLABAT	85.75	1.29	8.22	86.17	8.33	79.79	1.70	12.33	80.76	12.44
HATEM	81.50	4.11	20.73	84.07	20.47	66.30	9.00	33.26	74.79	34.46
HAYYAN	85.48	2.13	8.44	85.94	8.71	78.22	3.46	14.26	79.60	14.68
IZRIT	75.43	11.40	19.29	78.25	22.43	56.43	21.23	30.21	67.48	36.95
KARAK	65.25	0.69	1.65	65.29	1.80	45.31	2.32	6.72	45.87	7.11
MAAN A	77.32	2.53	8.45	77.85	8.85	66.05	4.39	14.85	67.91	15.64
MAAN B	75.38	2.41	8.43	75.90	8.78	65.31	3.68	16.98	67.59	17.38
SAHRAWI	82.51	2.91	10.23	83.20	10.64	70.31	6.47	19.02	73.17	20.15
TAFIH	82.71	2.76	9.43	83.29	9.83	75.01	4.30	14.28	76.51	14.93
TRAVERT	62.20	2.79	9.11	62.99	9.55	43.43	5.95	18.59	47.69	19.53
YANABI	79.97	3.59	10.47	80.75	11.10	69.19	6.35	22.28	73.07	23.19

The first six stones held the same ranks, Ballas has a better rank (7 compared to 9 in the dry state), Ma'an A has the same rank in both cases (8), Ma'an B slightly improved (9 compared to 10 in the dry state), Izrit drops in the ranking from 7 to 10, and finally Karak and travertine switched their ranks in the wet state. The ranking in both the dry and wet states is solely controlled by the color of the rock and cannot be associated with other properties such as lithology and porosity although these factors do influence the differential between the two (ΔE).

4. DISCUSSION AND CONCLUSIONS

As can be seen in Figures 1, 2 and 3 there are strong relations between the basic color components in the dry and wet states. Consequently the color in the wet state can be predicted from that of the dry state using the relationships of Figures 1-3. This will be useful from practical point of view to architects and other people involved in stone masonry and restoration projects.

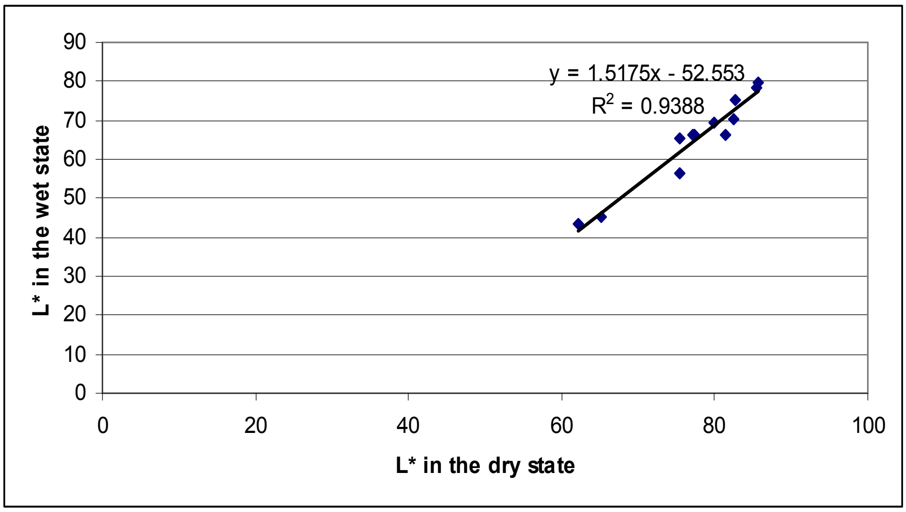

Figure 1 Deriving L* in the wet state from that of the dry state.

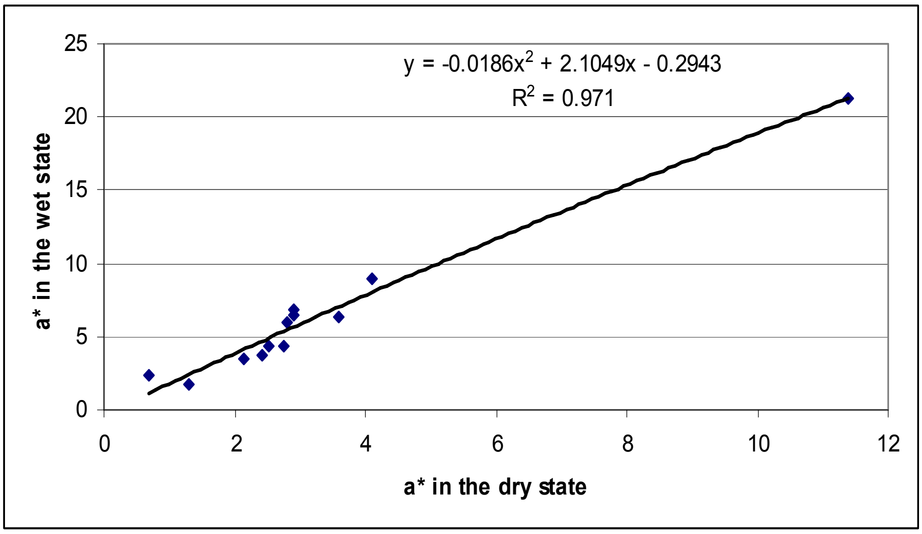

Figure 2 Deriving a* in the wet state from that of the dry state.

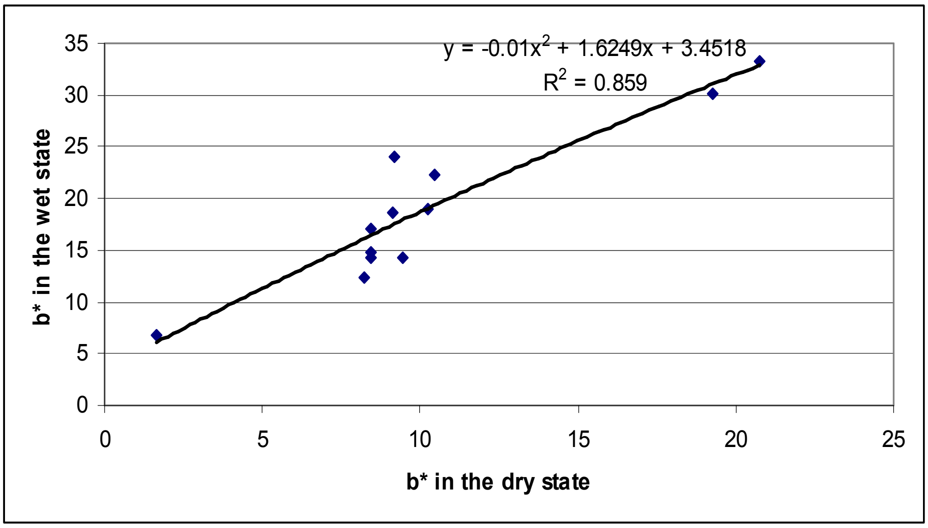

Figure 3 Deriving b* in the wet state from that of the dry state.

The absolute values of ΔE and ΔC are plotted in Figure 4. Although it is difficult for a curve to fit the different points, some sort of aggregation is evident. This aggregation is closely related to the texture and/or the color of the rock. Chalky rocks (Izrit and Hatem) constitute one group, Ajlun stones (Ballas and Yanabi) another, and crystalline limestones (Sahrawi: fine-crystalline, and travertine: coarse-crystalline) a third group. Fossiliferous creamy white limestones constitute a large group, with the possible Ma'an subgroup. Karak is plotted as a separate group characterized by high ΔE and low ΔC.

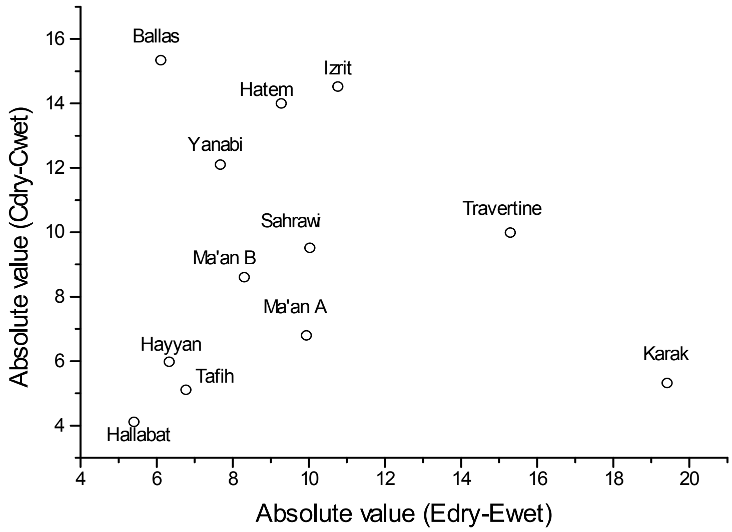

Figure 4 Correlation between ΔE and ΔC of the Jordanian building limestones between the dry and wet states.

These color changes (ΔE, ΔC) affect the aesthetics and sometimes the performance of building stone: stone used in buildings in positions particularly exposed to water will be a different color to those in drier locations. When using stones of different colors adjacent to each other, staining problems should be taken into consideration. Although it is known that the degree of polish and surface treatments affect color, it has not been possible to tackle these two factors in the present work.

The following conclusions can be drawn from this study:

- Stones used in buildings in positions particularly exposed to water will be a different color to those in drier locations.
- Color in the wet or soaked state can be derived from that of the dry state.
- When using stones of different colors adjacent to each other, staining problems should be taken into consideration.
- Color changes affect the aesthetics and sometimes the performance of building stone.
- The problem of inaccuracy in using the rock color chart is believed to be due to the low number of rock color chips (40) in the MRCC.
- In the dry state, the highest L* and E values were recorded in a creamy white coquinal limestone and the lowest in travertine. Chalk recorded the highest a*, b* and C values, whereas a gray-black limestone has the lowest b*, E and C values. In the wet state, the creamy white limestone has the highest L* and E values and the lowest a* value. Chalk has the highest a*, b* and C values. The gray-black limestone has the lowest b*, E and C values.

- Upon wetting L^* and E decrease, while a^*, b^* and C increase. The highest ΔE occurs in the gray-black limestones, an intermediate change occurs in fine and coarsely crystalline limestones, followed by colored chalks. Other types of limestone have a low change in E. In the case of ΔC, the greatest change occurs in colored chalks, followed by the very fine-grained limestone, crystalline rocks and finally the fossiliferous limestones.
- Despite the difficulty for a curve to fit the different points of the ΔE-ΔC graph, some sort of aggregation is evident. This aggregation is closely related to the texture and/or the color of the rock.

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